Analyzing AIRS data for evidence of stochastic forcing

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Motivation

- AIRS has given us 12+ years of high quality Top-Of-Atmosphere radiance data
- The high resolution AIRS channels allow us to probe different regions of the atmosphere (eg surface, strat T(z), trop T(z), trop WV(z), UT WV(z), stratospheric ozone)
- Climate studies with AIRS data now feasible eg trace gas rates, T(z) and WV(z) rates
- Accurate scattering models allow us to compare AIRS observational data with GCM model fields; first moment (biases) and second moment (standard deviations) give primary indications of GCM accuracy
- Higher PDF moments (third = skewness, fourth = kurtosis)

PDF Moments

Mean, StdDev, Skewness, Kurtosis are the 1st,2nd,3rd,4th moments of the (normalized) PDF

$$< x > = \mu = \int p(x)x\,dx$$

$$\sigma^2 = \int p(x)(x - \mu)^2\,dx$$

$$S = \frac{1}{\sigma^3} \int p(x)(x - \mu)^3\,dx$$

$$K = \frac{1}{\sigma^4} \int p(x)(x - \mu)^4\,dx$$
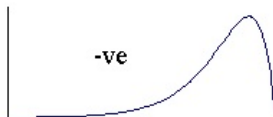
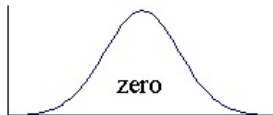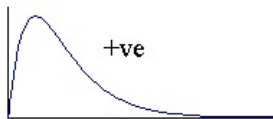Gaussian : skewness = 0, kurtosis = 3

PDF Moments

Sharply peaked distribution (less in the tails) : Kurtosis > 3
Wider distribution (more in the tails) : Kurtosis < 3
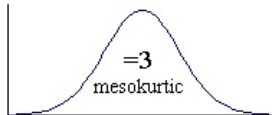"More stuff on the left" or "tail extending to right : Skewness > 0
"More stuff on the right" or "tail extending to left : Skewness < 0

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Previous work on atmospheric/ocean data

- Climate models "tuned" to reproduce mean,std dev (first, second moments)
- Use stats from "microphysical" locations (eg over multiple gridboxes) to look for "macroscopic" relationship
- Analyzing eg SST, sea level heights, 300 mb vorticity shows that
  - $K \geq 3/2 S^2 - r$
  - power law behavior in tails $pdf(x) = x^{-\alpha}$ for large x
- Can we model this?

Previous work on atmospheric/ocean data : Examples

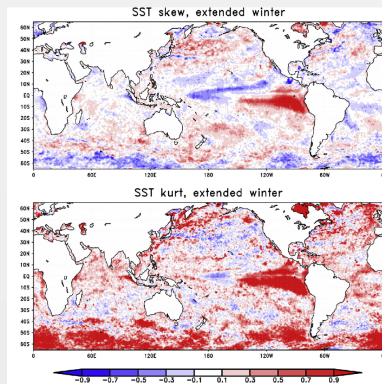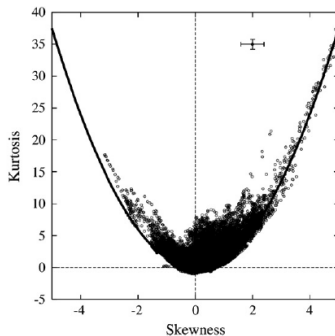atmospheric/ocean data eg SST, sea level height, 300 mb vorticity

Fig. 4. Scatter plot of excess kurtosis versus skewness for full-year SST anomalies equatorward of 65° North and South. The solid line denotes the function $K = (3/2)S^2$. The estimated local 95% confidence intervals on the values are indicated in the upper right corner of the figure.
Adapted from Sura and Sardeshmukh (2008).

Advances in stochastic modelling

YES : Take dynamics (forcings, linear terms, nonlinear terms) equations and separate out into slow and fast scales; the nonlinear interaction of fast scales leads to a SDE

Multiplicative noise in stochastically forced models can be shown to reproduce non-Gaussian statistics and power law behavior in PDF tails

$$\frac{dx}{dt} = a(x(t)) + b(x(t))\eta(t)$$

where a = deterministic slow processes, while $b\eta$ represents state dependent multiplicative noise [as opposed to state independent additive noise $a(x(t)) + \eta(t)$]; $\eta(t)$ is Gaussian white noise

Time dependent probability distribution function can be derived from SDE, from which the $K \geq \frac{3}{2}S^2 + B$ relationship and power law tails $pdf(x) = x^{-\alpha}$ for large x can be derived

Applications to AIRS data

- Radiative transfer for any AIRS channel is a convolution over multidimensional phase space (includes $T(z)$, $WV(z)$, other trace gases, surface temp, clouds etc)
- PDFS are extremely non-Gaussian, evidence of deviations from Gaussians in the tails (cold tail = clouds)
- Have shown our SARTA TwoSlab scatter code + ECMWF model fields produce simulations that agree quite well with more sophisticated MRO cloud simulators/DISORT scattering code
- How do the higher order obs/cal moments compare : Do they show $K \geq 3/2S^2 - r$?

Nighttime Ocean Scenes BT1231 cm^{-1}

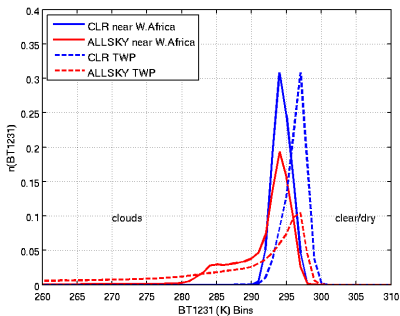Example : March 11, 2011 (2.9 million observations)
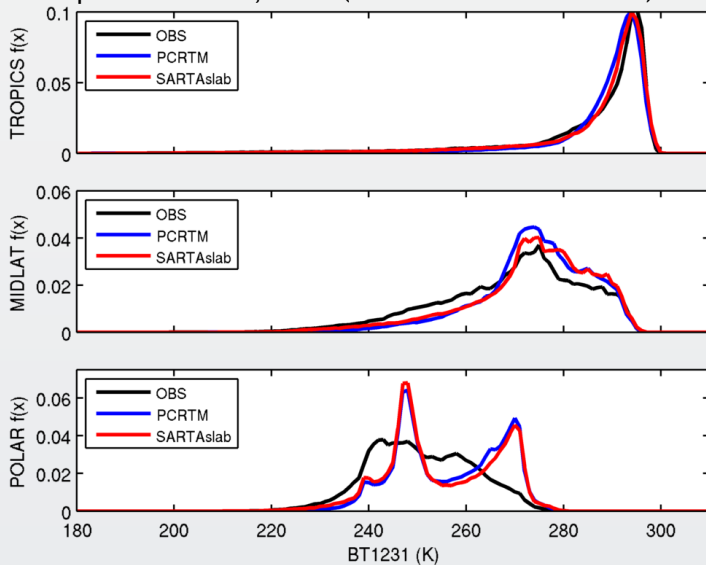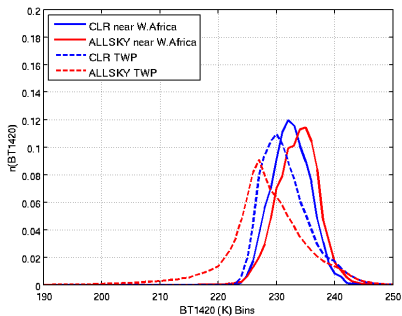
Nighttime Scenes 2 channels

Example : 10 years of AIRS data
CLEAR sky PDFs (blue) and ALLsky PDFs (red) for 2 channnels
The clear sky PDFs are closer (though not exactly) to Gaussian
while the allsky PDFs have tails due to clouds

1231 cm^{-1} (surface/window)   1420 cm^{-1} UT Humidity

AIRS data and SARTA calcs

CLEAR SKY

- can "filter" AIRS data for clear scenes, reducing entire daily observational data set by almost factor of 100
- colocate ERA geophysical, ran off SARTA clear
- collect 10 year stats into 4°bins, separated by day/night (DN), land/ocean (LO) and season (DJF/MAM/JJA/SON)

ALLSKY

- AIRS nadir tracks (index 45,46) 10 year record, over all geographical regions (approximately 100 million data points)
- colocate ERA geophysical and cloud fields, ran off SARTA scatter (TwoSlab)
- collect 10 year stats into 4°bins, separated by day/night (DN), land/ocean (LO) and season (DJF/MAM/JJA/SON) (approximately 6000 points per tropical bin)
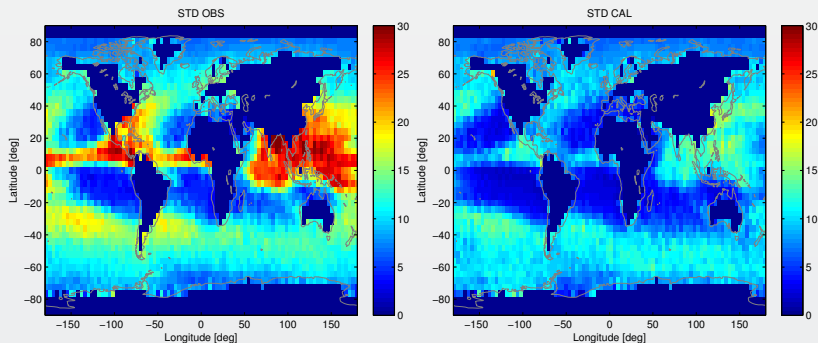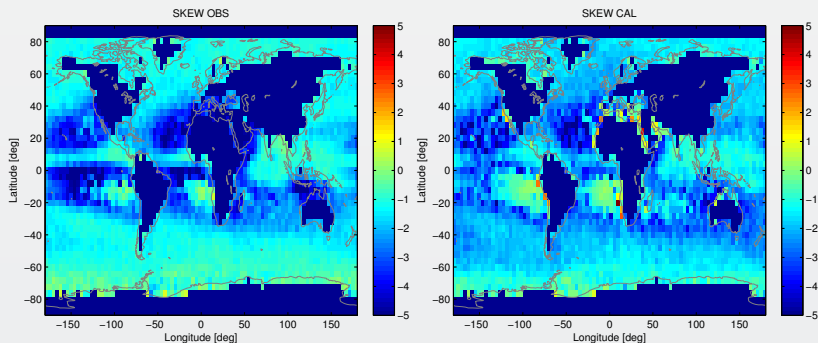
Summer AllSky : Mean Obs/Cal for 1231 cm^{-1}
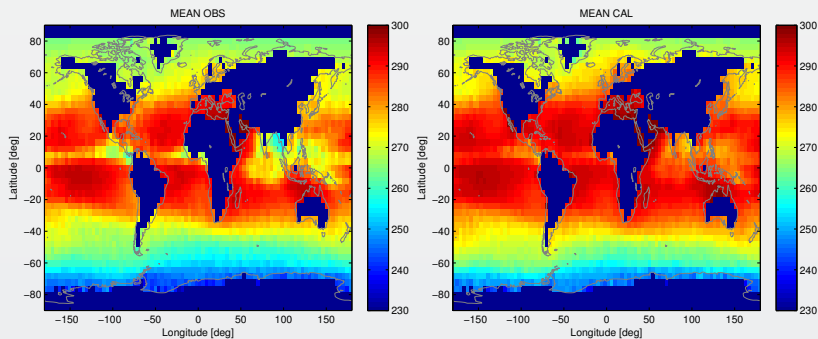
OBS   CAL

Summer AllSky : StdDev Obs/Cal for 1231 cm^{-1}
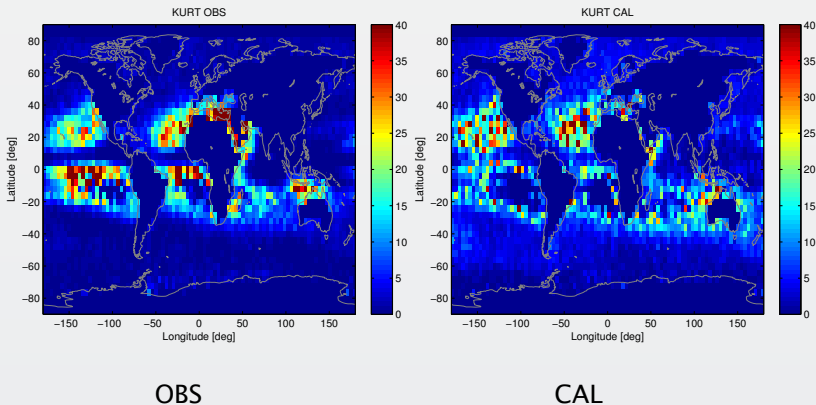

OBS   CAL
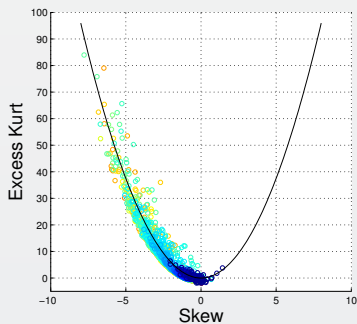
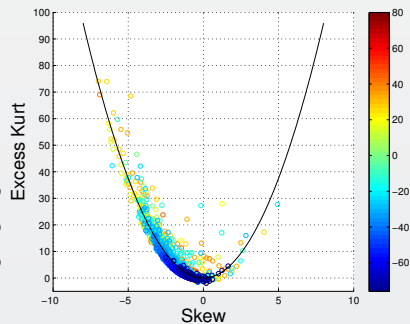# Summer AllSky : Skew Obs/Cal for 1231 cm^{-1}

OBS   CAL

Summer AllSky : Kurt Obs/Cal for 1231 cm^{-1}

OBS   CAL

AllSky Summer Kurt vs Skew for 1231 cm^{-1}
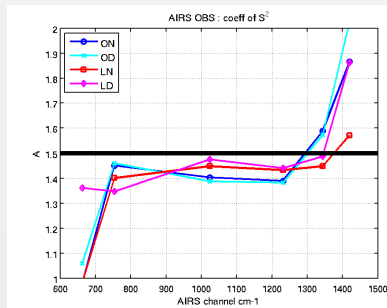

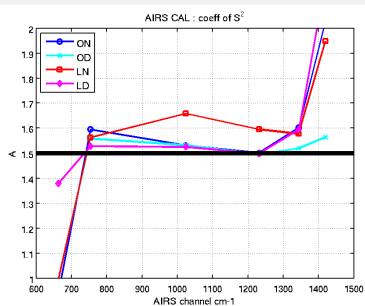OBS   CAL

AllSky Kurt vs Skew for different channels

$K \geq 3/2 S^2 - r$
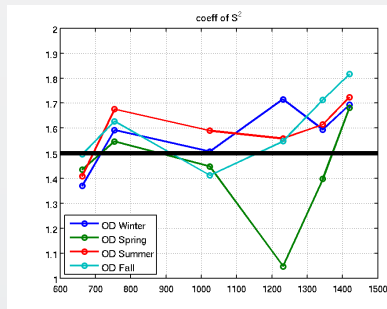

coeff of S^2 (OBS)   coeff of S^2 (CAL)
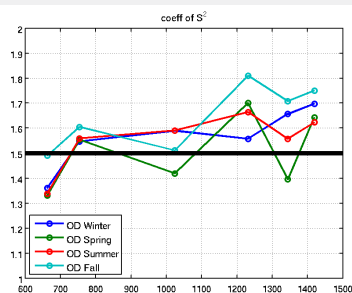
Clear Sky Kurt vs Skew for different channels ALL SEASONS (L) Obs and (R) Cal

OD = ocean day; expect $K \geq 3/2 S^2 - r$
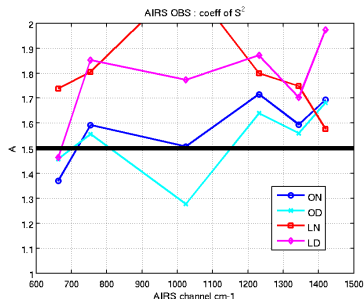

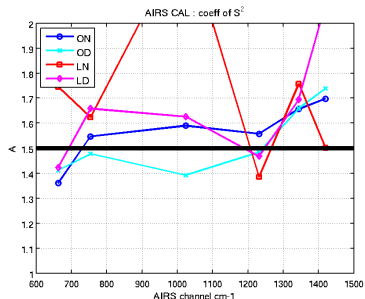coeff of S^2 (OBS)   coeff of S^2 (CAL)

Clear Sky Kurt vs Skew for different channels WINTER Obs vs Cal

OD/ON = ocean day/ocean night
LD/LN = land day/land night
expect $K \geq 3/2S^2 - r$

coeff of S^2 (OBS)   coeff of S^2 (CAL)

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Conclusions

- In general channels we examined do show evidence of stochastic forcing
  - $K \geq 3/2S^2 - r$
  - power law behavior in tails $pdf(x) = x^{-\alpha}$ for large x
- High altitude $T(z)$ channels much quieter, except daytime over land?
- AIRS measurements include stemp, temp(z), WV(z), clouds
  - can we understand the multi-dimentional behaviour in terms of these 1D results?
  - Should we bin the obs in terms of BT1231 eg $\geq$ 300 K convection, $\geq$ 290 K stratus, $\geq$ 270 K altostratus, $\leq$ 270 K cirrus and $\leq$ 230 K DCC??
  - allsky data has $1.3S^2 \leq K \leq 1.5S^2$; compare to allsky calcs (NWP models) which show $1.5S^2 \leq K \leq 1.7S^2$
  - Conversely clear sky obs/cal data has $1.4S^2 \leq K \leq 1.8S^2$

Stochastic theory material : preprints available on P. Sura's website